



# Soldier as a System Value Analysis

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## Executive Summary

**Problem Definition** The Army's Program Executive Office (PEO) – Soldier is focused on developing and fielding the best equipment for Soldiers to ensure domination across the full spectrum of military operations. The Army recognizes that the Soldier is the centerpiece of its combat systems and formations and PEO Soldier has the challenge of integrating and equipping the Soldier as a System. However, some elements of the system remain consistently under-funded such as those that protect Soldiers from adverse environmental conditions, provide for health and comfort needs, support ergonomic requirements and ensure the ability of the Soldier to operate effectively in any environment for extended periods of time. At issue is the ability to quantify the impact of products that support the human component on Soldier effectiveness and capabilities. While intuitively a Soldier's quality of life and physical well being impact the ability to accomplish the mission and take full advantage of the extraordinary technical capabilities provided to them, that argument does not carry enough weight in the budget fight to be effective on its own. This research seeks to provide PEO Soldier with a framework for evaluating the impact of programs that provide for quality of life, comfort, and environmental protection with tangible metrics based on value in terms of Soldier effectiveness.

**Technical Approach** The approach to this research effort is to use established quantitative methods in the development of the framework and explore possible metrics for the assessment of applicable products and programs.

- Conduct a literature review on the impact of adverse physical conditions on human performance and efficiency, as well as the Soldier as a System concept.
- Document evidence of the importance of human performance on the capabilities of the Soldier as a System.
- Conduct analysis of the objectives and values of the Soldier as a System, including key functions, capabilities, and constraints.
- Apply concepts from value focused thinking and other decision analysis and support theories to the Soldier as a System equipping problem in support of the framework development.
- Develop a framework for the quantitative assessment of applicable products and programs that map to Soldier as a System capabilities.

**Results** Much of the work in this research focused on problem definition and refinement, specifically how and what to quantify in terms of metrics for human performance. An extensive literature review found that much of the research on human performance focuses on discrete tasks and controlled environments. Soldier related research was most prevalent in the areas of short term fatigue, workload, carrying load, and sleep deprivation. The dearth of evidence on the impacts of adverse conditions over the long term is logical because of the logistical and ethical hurdles that confront the kind of experimentation that would be required. It is not feasible or ethical to expose a human to extreme conditions and combat tasks, without proper equipment or protection, simply for scientific purposes. However, many examples of human factors in military operations exist, both anecdotally and through inference. LTG James Peake, former US Army Surgeon General, notes that indifference to environmental conditions can be disastrous, noting the German invasion of Russia in World War II as an example, and calls harsh environments great, silent, debilitating agents for military operations. Similarly, evidence exists for the impact of material solutions on human performance, such as

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the non-linear debilitation factor of cold on manual dexterity. While this is an important factor for Soldiers in harsh environments, it is difficult to translate into a metric associated with Soldier as a System capabilities.

Hence, another element of the research focused on the Soldier as a System concept. The intent of the Soldier as a System is to replace haphazard fielding efforts with an approach that treats the Soldier just like the other complex combat assets in the Army arsenal by integrating systems with desired capabilities of the Soldier in order to ensure battlefield dominance. An important element of this concept is inclusion of the human as a component of the system, specifically noting that the concept seeks to equip the man instead of manning the equipment. This indicates the importance of the human in the Soldier as a System with respect to other, more high tech programs. This is the underpinning for an assessment framework that elevates the human to the fundamental component upon which all other elements of the system build upon.

The development of an assessment framework required the extraction of key functions and values of the system, a component of the decision analysis concepts applied to this problem, including value focused thinking. The key functions include shoot, move, communicate, maintain situational awareness, and survive. The values associated with the Soldier as a System include versatile, responsive, deployable, interoperable, reliable, robust, sustainable, trained, efficient and effective. Influence diagramming was also used to illustrate the relationship between the elements of the system and set the structure of the framework. Given that the state of the human component influences the functions of the systems, an assessment framework can follow that same pattern. If you know the impact of the product on human factors, and you know the relationship between the human factor and the system capability, then you can demonstrate the impact of the product on the capability of the Soldier as a System. The relationship between human factors and system capability can be mapped with an “If-Then-So” construct, such that if the Soldier has/can do/is X, then they will be/maintain/sustain Y, so they will be able to do Z, where X represents human body metrics, Y represents human factors, and Z represents Soldier as a System functions and capabilities. The question then becomes what metrics and measures to use in the assessment of the human component and how products from programs that focus on that element of the Soldier as a System impact the human condition and performance in the short and long term. While some product specifications may be applicable, much of the data points in question are more subjective than measurable, such as fit and comfort, so user feedback becomes a critical component of the assessment framework. Future work may include the creation of data collection vehicles and actual data collection for certain products. The contribution of this framework is the linkage between data ready and relevant human factors with Soldier as a System functions. This concept will help PEO Soldier demonstrate the importance and value of programs that focus on the human component of the Soldier, particularly in adverse conditions.

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## 1 Introduction

The Soldier is the most important, capable, all-weather, deployable, employed, vulnerable, and complex combat platform in the nation's arsenal. The Soldier as a System (SaaS) concept is an integrated methodology for equipping in order to optimize Soldier effectiveness, and includes the Soldier and all those items worn, carried, or consumed. The needs of human factors in the SaaS are clearly compelling but often under-represented in funding priorities. Soldiers are required to operate effectively for extended periods across the full spectrum of military operations and environmental conditions, which can place enormous stress on the human component of the system, both short and long term. PEO Soldier strives to provide the best equipment to ensure the success and dominance of Soldiers. However, currently Soldier equipment is funded in a piecemeal manner instead of as a holistic weapon system. Weapons, sensors, and other components compete for funding, often based on their contribution to key capabilities. Indicative of the need to emphasize human factors in the SaaS package is the reluctance to fund items perceived as comfort items instead of viewing them as critical to the human element of the system. However, these items ensure the critical capabilities like lethality of the Soldier, who is the fundamental component of the system. The value of clothing and equipment items that provide environmental protection are difficult to quantify, thus at risk for under-funding. This in turn puts the SaaS at risk for diminished effectiveness. Demonstrating the impact on Soldier performance of difficult to quantify items will help the SaaS support funding decisions and ensure the effectiveness of the system. Ultimately, the goal of this research is to establish a methodology for determining the value in terms of Soldier effectiveness of such programs. This is accomplished by using systems thinking and decision analysis concepts to assess impact on effectiveness and critical capabilities. This project combines human factors, systems engineering, value focused thinking, and decision analysis to recommend policy for the development and implementation of SaaS technology, emphasizing the importance of a holistic

and human-centric approach to valuing the components of the SaaS.

Based on funding patterns, the Army sees significant value in certain programs and material solutions provided by PEO Soldier. These areas of recognized value include those that provide well defined and measurable capabilities, such as lethality and tactical awareness. However, the material solutions that support the idea of viewing the Soldier as a weapon system have been consistently under-funded in the base budget. For example, the rollup of the current programmed budget for FY 09-13 funds 75% of the Sensors and Lasers program requirement but just 16% of the clothing and individual equipment (CIE) program requirement. These programs include items that protect Soldiers from adverse environmental conditions, provide for health and comfort needs, support ergonomic requirements, and ensure the soldier's ability to operate effectively for extended operations.

Intuitively, a Soldier whose basic physical needs are met will be more able to accomplish the mission than if they are not. These needs may include warmth and the ability to maneuver without discomfort for long periods and they logically have an impact on the ability to sustain operations at a highly effective level, both physiologically and mentally. Conversely, a Soldier who is constantly battling the elements, or cannot rest when able because of discomfort, will experience degraded effectiveness. As a result, they will not be able to take full advantage of the extraordinary capabilities of high tech equipment, much of it provided by PEO Soldier. Hence, when certain items go under-funded the effectiveness of the Soldier is diminished.

There are currently no metrics established to demonstrate the effectiveness of these items. Therefore, any argument in support of programs that provide comfort and environmental protection to Soldiers has been less successful than those for other, more clearly measurable programs. This research seeks to support the "Soldier as a Weapon System" by providing data and analysis of the impact of PEO Soldier programs that provide for Soldiers quality of life, comfort, and environmental protection during high intensity, long

duration operations. Ultimately, the goal of this research is to establish a tangible set of metrics to determine the value in terms of Soldier effectiveness of such programs.

## 2 Background

### 2.1 PEO Soldier

In April 2002, the Assistant Secretary of the Army for Acquisition, Logistics, and Technology established Team Soldier at Fort Belvoir, Virginia, with one mission: to develop, acquire, field, and sustain virtually everything the Soldier wears, carries, and operates to increase combat effectiveness, save Soldiers' lives, and improve Soldiers' quality of life. PEO Soldier was created to ensure our Soldiers remain second to none in missions that span the full spectrum of military operations (PEO Soldier, 2007). It was also an effort to start treating the Soldier like other combat platforms, as a system (Crozier, 2006). PEO Soldier is dedicated to equipping Soldiers to enable peak performance across the spectrum of military operations, and provide the ability to accomplish tasks and function in an integrated manner with increased confidence, while also saving Soldiers' lives and enhancing the quality of life (PEO Soldier, 2007). The creation of PEO Soldier was a major step towards the realization of improved, SaaS material acquisition (Lockhart, 2006). SaaS approaches equipping the Soldier as an "integrated fighting system just as any combat vehicle or aircraft" (PEO Soldier, 2005). Applications of the Soldier as a System concept by PEO Soldier in equipment development focus on integrating components to increase effectiveness, decrease combat load, and improve mission flexibility (Crozier, 2006). This is particularly important given the fact that Soldiers are continuously exposed to harsh and varied environmental conditions.

### 2.2 Soldier as a System

Army leadership recognizes the Soldier as the single most important resource in the Army for accomplish-

ing missions and winning wars, as well as its most vulnerable asset, susceptible to almost every threat known on the battlefield (US Army Training and Doctrine Command, 2006). The Army Vision states that the Soldier is the centerpiece of the Army, which is a force that is responsive and dominant across the full spectrum of possible conflict and military operations, strategically responsive, deployable, agile, lethal, survivable, sustainable, and versatile (Office of the Chief of Staff of the Army, 2003). This is reiterated in the 2006 Army Posture Statement, Joint Vision 2020, and the 2005 Army Modernization Plan. Attaining the goal of full spectrum dominance requires a steady infusion of new technology, modernization, material superiority, as well as an integrated methodology for equipping Soldiers, known as the Soldier as a System concept (Lockhart, 2006). History gives many examples of the need for addressing the Soldier as a system. In the past, haphazard and un-integrated efforts resulted in the "fielding of equipment that was heavy, bulky, and burdensome" which degraded Soldier effectiveness and performance instead of enhancing it (US Army Training and Doctrine Command, 2006). An integrated and modular system of systems approach would provide for the Soldier while also considering the boundaries and norms of common human performance (PEO Soldier, 2005). Since World War 2, the Army has "succeeded in maximizing technological advancement in weapons but has failed to capture the potential value of treating our most important resource – the Soldier – as a system." The Army Science Board 1991 first proposed the SaaS based on the complexity of properly equipping the Soldier for combat, the fact that existing equipment mismatches reduced combat efficiency and endangered Soldiers, and the need for promising new technology to be exploited to ensure battlefield dominance (Lockhart, 2006). The SaaS Initial Capabilities Document 2005 emphasizes the importance of treating the Soldier holistically to allow the system to compete effectively with other major combat programs for funding and resources. Optimizing Soldier capabilities will in turn impact total force capability and effectiveness (PEO Soldier, 2005).

The Joint Vision 2020 envisions a full spectrum dom-

inant force that is persuasive in peace, decisive in war, and preeminent in any form of conflict, which requires Soldier as a System capabilities that directly support operational capabilities. Soldier as a System concept provides more favorable conditions for Soldiers to accomplish their individual tasks, and possibly to higher standards, by striving to improve the conditions all Soldiers must function under (US Army Training and Doctrine Command, 2006). Significant improvement in Soldier effectiveness is possible only with changes in the way the Soldier is conceptualized and equipped. However, SaaS is about more than just material solutions and acquisition transformation. It seeks to optimize Soldier effectiveness by fully integrating the Soldier with his equipment (Lockhart, 2006). It also provides a formal approach to addressing and integrating all Soldier capabilities and needs, establishing baseline capabilities to derive modernization efforts. It seeks to improve Soldier capabilities by focusing on lethality, survivability, mobility, sustainability, and battle command/situational awareness and using metrics such as performance, power, weight, volume, cost, training, and criticality of need (PEO Soldier, 2005). In total, SaaS is intended to enhance the individual Soldier's capabilities to accomplish assigned tasks across the full spectrum of conflict, in any operational environment (US Army Training and Doctrine Command, 2006).

While much progress has been made in implementing the SaaS concept, a key component remains. The linkage between required capabilities and the funding for such capabilities is imperative in order to prevent inadequate funding. Delayed funding will directly impact the technology development required to maintain the Soldier's cutting edge and ensure full spectrum dominance in all operational environments (Lockhart, 2006). Currently, CIE is the last remaining program funding issue that has not migrated from supplemental to base funding. Given the political and funding environment, those items that protect the Soldier from harsh conditions and allow for operations in any environment are a risk.

### **2.3 Capabilities Requirements**

Critical to shielding elements of the Soldier as a System that protect from harsh environmental conditions and provide for quality of life from funding shortfalls is demonstrating their value in terms of Soldier effectiveness. This requires a defined link between them and key Soldier capabilities. In order to dominate any opponent in any environment, the Soldier must have exceptionally high levels of capabilities in the areas of mobility, lethality, situational awareness, survivability, and sustainability. Survivability involves "effective protection and survival within the full spectrum of military operations and in all operational environments." Mobility includes the ability to maneuver across the full spectrum of military operations in all operational environments (US Army Training and Doctrine Command, 2006). Lethality is the capability to detect, identify, and employ lethal and non-lethal effects against appropriate targets through the full spectrum of military operations under all climatic conditions and operational environments. Survivability involves the ability to counter, withstand and/or survive all natural and manmade hostile environments within the full spectrum of military operations (PEO Soldier, 2005). Sustainability incorporates physical, spiritual, social, mental, and physical health and performance of the Soldier across the full spectrum and duration of military operations and in all environments in order to minimize the risk of failure. Situational awareness includes the ability to perceive, comprehend, and exchange real time information across the full spectrum of military operations, under all climatic conditions, and all environments. The Soldier system should enhance the autonomous ability to perform effectively. The soldier should be able to be resupplied in all climatic conditions and in all environments. Soldiers must have enhanced physiological and physical capabilities in the operational environment. Soldiers must excel at critical thinking, be adaptable to a variety of situations, be able to leverage technologies, and have enhanced endurance and stamina to fight effectively under all environmental conditions in all operational environments (US Army Training and Doctrine Command, 2006). Ideally, Soldiers operate at

the optimal level of human functioning and cognitive performance, given the tasks they are required to perform such as vigilance, exercising good judgment, applying lethal force, and protecting themselves in a hostile environment (Miller et al., 2007). This optimal performance is critical to success on the modern battlefield over the course of the long war.

Material solutions can greatly impact the Soldier by providing combat overmatch and enhanced capabilities, but they may also affect personal conditions and soldier load, which is why interoperability and compatibility between equipment systems is extremely important (US Army Training and Doctrine Command, 2006). This is also why consideration for quality of life, fit, comfort and ease of use is an important part of the development of the holistic Soldier system. Small details can make a big difference to a Soldier in harsh conditions over long periods of time.

### 3 Human Performance Literature Review

Part of the approach to this research is a literature review of documented evidence of the impact of adverse environmental conditions on human performance, particularly in war time conditions. The purpose is to provide support to the intuitive sense and anecdotal evidence that adverse environmental conditions directly affect Soldier performance and should be addressed as an integral part of the Soldier as a System. This is not a trivial task due to the complexity involved in studying the human being and the challenge of finding appropriate means, measures, and metrics to determine impact. Much of the emphasis in human performance research revolves around single task performance, workload or physical load, and athletic competition or feats. The challenge in documenting long term impacts of environmental conditions include limitations to creating realistic stress factors in a laboratory environment, as well as the interactions of life science and physiology, engineering and textiles, and behavioral sciences, which all have an impact on human performance. This section will explore examples in military

history, scientific studies and findings, and the impact of material solutions related to human performance in adverse environmental conditions.

#### 3.1 Examples in History

History is full of examples of the devastating effects of environmental factors on the outcome of battles, campaigns, and wars. LTG James Peake, US Army Surgeon General noted that harsh environments are great, silent, debilitating agents for military operations and indifference to environmental conditions can contribute as much to defeat as the tactics of the enemy (Pandolf and Burr, 2001). The unexpected failure of the German invasion across the Finnish-Russian border in July 1941 to capture a strategically important railroad near the Arctic Circle is an example of the operational impact of adverse conditions. Their heavy woolen uniforms were ill suited for the heat, humidity, constant sunlight, and mosquitoes. Commanders failed to anticipate the impact on combat effectiveness of these factors and the mission was called off after the force only advanced 13 miles in nearly a month (Pandolf and Burr, 2001). Similarly, Napoleon's attack on Moscow was broken by winter conditions and Alexander the Great's forces suffered from snow blindness and severe cold in central Asia, resulting in massive losses. In World War I, alpine battles between Italians and Austrians saw more injuries from the steep, broken terrain and cold conditions than from actual combat. Troops not wearing a special cold weather boot tested during the Italy campaign during World War II suffered immersion foot, causing thousands of casualties and many amputations. During the retreat from the Chosin Reservoir in Korea, wintry cold was extreme while clothing and footwear suitable for garrison duty were inadequate, causing most of the survivors to suffer hypothermia, frostbite, and/or amputations (Pandolf and Burr, 2001). Other examples of the effect of environmental conditions on military operations include the impact of heat in North Africa in World War II, heat and humidity impact in Southeast Asia, cold weather injuries in the Aleutian Islands in World War II, hypothermia deaths in Ranger School in 1976

and 1995, performance impact of rapid ascent to over 10,000 feet in Afghanistan. All are results of an underestimation of environmental risks (Friedl and Allan, 2004). Since many of the resulting casualties in these situations were preventable, this is not a comfort issue; it is a safety and force protection issue.

### 3.2 Scientific Studies and Findings

The U.S. Army Research Institute of Environmental Medicine (USARIEM) conducts basic and applied research into environmental factors that affect the health and performance of military personnel. They use special facilities such as heat and cold chambers to conduct research into potential enhancements to Soldier capabilities that prevent the degradation of performance due to environmental conditions. These efforts are intended to aid policy makers and material developers. USARIEM Commander COL Karl Friedl notes that as long as warfighters are challenged to the limits of their mental and physical capabilities in harsh environments the relationship between physical characteristics and physiological states and Soldier performance will be important (Friedl and Allan, 2004).

Different kinds of environmental stressors include heat, cold, hypobaric hypoxia, physical work, energy deficiency, biodynamic forces, sleep deficiency, anxiety and fear. Multiple stressors can also interact and threaten the health and performance of Soldiers in operational environments. Soldier problems almost always involve more than one stressor in field environments, and the interactions may be just as critical as the individual impacts (Friedl and Allan, 2004).

The ability of the human body to adjust to significant environmental stressors, such as heat, depends on several factors including the type of clothing worn and the availability of fluids. Intense heat and high humidity can increase oxygen consumption and even when the same work is performed, subjects in these kinds of environments experience added thermal stress, which forces the body to work harder to protect it from overheating. With respect to clothing, it is important that the materials worn obstruct heat

transfer as little as possible to ensure evaporative cooling (Lau, 1996). Sources of heat that impact military operations include metabolic heat production from extreme work efforts, the combination of heat and humidity particularly in crew compartments, and the difficulty in cooling while wearing highly insulating clothing and protective gear. Clothing can limit sweat evaporative cooling, particularly if it is heavily insulated or relatively impermeable. While this may be relatively unavoidable in protective gear, the development of actual clothing items that reduce these factors can make an impact on the Soldier's ability to manage extreme heat environments (Pandolf and Burr, 2001). The report by Wai-Man Lau investigates the physiological impact of environmental stressors on Australian Defence Force personnel in a particular region of Australia characterized by unforgiving climatic conditions (specifically heat and high humidity) and difficult terrain. It reviews physiological requirements and limits for soldiers, environmental stressors that impose physiological stress on soldiers, and options for minimizing injury due to environmental stressors (Lau, 1996). Key findings of the research in Australia include the rapid deterioration in both physical and mental performance when working in a hot environment, the impact of dust storms and strong winds as a factor in reducing capabilities, and the need for a better Australian Army uniform to aid evaporative cooling (Lau, 1996).

Extreme environments are not limited to geographic location; they can also be caused by fighting platforms, such as armored vehicles. The temperatures and humidity inside such common combat vehicles can be significantly more extreme than the natural environment, with little safe opportunity for relief. Thus, the importance of clothing that does not make the situation even worse becomes even more pronounced. In particular, high humidity caused by evaporated sweat, combined with high temperatures, trapped next to the skin by clothing that limits moisture permeability greatly increases the heat casualty risk (Pandolf and Burr, 2001). "Heat stress results from the interaction of climatic conditions, body heat production, and the wearing of clothing or equipment or both that impedes heat loss. Heat stress gener-

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ates a need for sweating and circulatory responses to dissipate body heat, especially when the environment is warmer than skin, and may push the body's homeostatic systems to their limits." Wearing clothing that is inappropriate to the environment and level of metabolic heat production can cause heat stress even in cool environments (Pandolf and Burr, 2001).

Military operations can be conducted successfully in cold weather climates, as demonstrated in World War II European campaigns, Korea, Balkans and Afghanistan, even though extended exposure can push Soldiers to their physiological limits. However, such conditions can impair the ability to execute required functions and influence Soldier health and individual performance (Department of the Army, 2005). Cold stress, including extremely low temperatures as well as cold-wet exposures, requires management in order to ensure successful mission accomplishment (Department of the Army, 2005). Mission completeness may be delayed in cold conditions because of physical performance decrements and slower movement of personnel encumbered by protective gear or physically impacted by the conditions. For every 1.8 degrees Fahrenheit decrease in body temperature, max endurance capability decreases by about 5%, endurance time decreases by 20%, and max strength and power output is decreased by 5% (Department of the Army, 2005). Body temperature is normally regulated in two ways, physiologically and behaviorally (Department of the Army, 2005). However, in operational environments, the behavioral efforts are often overridden by mission requirement because they do not fit in appropriately. For example, part of behavioral thermoregulation is reducing cold exposure with clothing, but if that clothing limits mobility when mobility is essential, Soldiers and leaders may chose to forgo cold weather gear, leaving them even more exposed to the effects of the environmental conditions. Intense physical activity, limited food, and significant sleep deprivation disrupt the body's normal physiological responses to cold, so operational conditions make cold stress management even more difficult than is experienced non-military activities (Department of the Army, 2005). Integrating the environmental protective gear with the Soldier as a

system is critical to providing useful protection from extreme environments. Also, the lack of behavioral regulation increases the requirements on the physiological responses, which in cold environments means increased shivering, which in turn have a negative effect on the ability of the Soldier to accomplish individual tasks such as engaging a target. Cold weather also contributes to disease and other non-combat injuries, which ultimately degrade the effectiveness and capabilities of the force (Department of the Army, 2005).

As skin temperatures decline (even if the body core temperature remains normal), pain sensations increase, manual dexterity declines, joint mobility decreases, and tactile sensitivity is reduced. For example, immersion of hands and forearms in 50 degrees Fahrenheit water for 5 minutes can decrease manual dexterity by 20-50%. The physical impact is not linearly related to the temperature, instead the colder the skin gets the more dramatic the decline in performance. Cold hands and fingers can cause a significant decline in performance of gross and fine motor skills, hence the importance of gloves that preserve functionality and effectively protect from cold temperatures. Also, the duration of cold exposure has an impact, as underlying tissues and nerves cool, greater declines in performance occur. (Department of the Army, 2005) Physiological and psychological responses to cold environments can also degrade mental performance on complex thinking tasks by 17-20%. Memory is impaired and vigilance decrements occur when body temperature falls. Low ambient temperatures that impact skin temperatures impair tracking responses that require continuous rapid accurate responses by 13% and short term memory declines up to 20%, even if the body temperature remains normal. (Department of the Army, 2005) Ultimately, "excessive cold stress degrades physical performance capabilities, significantly impacts morale, and eventually causes cold casualties." (Department of the Army, 2005)

Strong winds and dust storms can deteriorate physical performance by causing significant irritation to eyes and soft tissue, skin abrasions or rashes, and nose or throat bleeding due to membrane damage.

Therefore, protection from these environmental conditions is important (Lau, 1996). Extended direct sun exposure to the skin can cause painful or even debilitating sunburn or poisoning, and sun glare can hurt the eyes and affect the Soldier's ability to track enemy movement or sense battlefield conditions (Lau, 1996).

### 3.3 Impact of Material Solutions

In recent times, the US has conducted military operations in the full spectrum of environmental conditions, from hot climates such as Haiti, Somalia, and Iraq, to cold climates such as Korea and the Balkans, to mountain terrains such as the Balkans and Afghanistan. This will continue to be true. However, a theme in the historical examples is the failure to appreciate lessons from past operations in harsh environmental conditions, including the failure to anticipate the impact of the environment and provide adequate or improved clothing, footwear, and other protective materials. This may be in part due to cultural mindset in the military that encourages stoic self-denial. Shay says that pretending to be superhuman is very dangerous, especially in a long term combat environment. "We must stop handing the enemy a dangerous and unearned advantage" (Shay, 1998). The "myth of the warrior" is not uncommon in the military environment. It is the belief that fatigue and other physical human conditions can be overcome by adequate motivation. However, this attitude flies in the face of the need to for Soldiers to perform at optimal levels. While Soldiers may be able to perform with that mentality, it would not be at the highest levels of human capabilities. Warfare is a non-stop activity that requires highly skilled operators of highly complex systems in demanding operational conditions. Any degradation in human performance will have a direct impact on the ability to meet the requirements of the mission (Miller et al., 2007). Approaches to protecting Soldiers from the "myth of warrior" include education and acknowledgement of the impact on human performance of environmental conditions and the need to control those influences on the battlefield, as well as improved ma-

terial solutions and technologies. The reality is that an inflexible boundary of human capacity exists, and operating anywhere in the vicinity of that limit is dangerous and ineffective. "It is imperative that we acknowledge these human limitations" and respond to environmental impacts with these limitations in mind (Miller et al., 2007).

Humans are continuously pushing the envelope of what is considered the range of possibility of operations in extreme environments. How "extreme" is defined changes, in part due to the inherent faith in our ability to do so as well as technology that affords humans the ability to expand boundaries. Think space travel, arctic exploration, cave diving, etc. A significant question for researchers and designers is what the next generation of extreme will be and what support will be needed for humans operating in that environment. (Hancock et al., 2007) Warfighters need the ability to reduce the risks related to environmental extremes, but designers must balance the benefits to the user of advanced clothing and individual equipment with the physiological tradeoffs, such as freedom of movement.(Friedl and Allan, 2004). For example, bulky cold weather clothing may actually increase energy requirements on Soldiers operating in extreme cold environments (Friedl and Allan, 2004). Similarly, the insulation factor of clothing worn can have a direct impact on the vulnerability of Soldiers to the effects of heat because it can be translated into an impact on effective temperature. This insulation limits heat loss and affects the body's natural cooling mechanism. Each incremental increase in the insulation factor increases the ambient air temperature by 1-2 degrees Fahrenheit. Extensive research shows the impact of heat exposure on the ability to sustain or manage work loads. New materials that aid in, or have less negative impact on, the ability of the body to manage heat stress, could logically impact the work load capability of the Soldier and reduce the risk on performance in intense heat environments (Pandolf and Burr, 2001). A material solution that could decrease the insulation factor, compared to current clothing options, would reduce the effective temperature of the Soldier, and thus reduce the risk of a heat casualty (Pandolf and Burr, 2001).

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Efforts to develop technology that enhances survival, protection and physical performance of military personnel in adverse environments include new clothing fabrics intended for different environments, integrating protection into new uniform items, and textile advances that reduce physiological strain that results from environmental stressors (Lau, 1996). Goals for material solutions with respect to environmental stressors should include owning the environment, optimizing materials to human tolerances, extending physical capacity without injury or increased burden, preventing Soldier system failure, and ensuring effectiveness of protective equipment and Soldiers (Friedl and Allan, 2004). A systematic, holistic design to equipping Soldiers will enhance their ability to accomplish individual and collective tasks, improve quality of life, build confidence, and save lives (Lockhart, 2006). Taking into consideration the perspective of Soldiers is critical in the development of equipment, ensuring that items are designed for the Soldier instead of the Soldier having to adapt to the equipment. Equipment must be comfortable, durable, and able to perform with the Soldier in combat (Crozier, 2006). Other key considerations for Soldier equipment are its additional encumbrances on the Soldier and how it interacts with other equipment or clothing. Minimizing additional burden is just as important as providing capability.

The new Extended Cold Weather Clothing System (ECWCS) is an example of innovative textile solutions designed with the operational Soldier in mind. It builds on industry knowledge of what professional outdoorsmen and mountain climbers would wear, validating the effectiveness and usefulness in extreme, real world environments, and encompasses what the Soldier needs by being more comfortable, less bulky, lighter, more compressible, easier to wear, more functional, more flexible, and easier to pack than the current generation of cold weather gear (Crozier, 2006).

In implementing the SaaS concepts, PEO Soldier developed the Rapid Fielding Initiative (RFI) and the Soldier Enhancement Program (SEP) to meet the specialized equipment needs of Soldiers in deployed environments (Dawson, 2006). The existence and success of RFI and SEP programs demonstrate the

need that Soldiers have for improved and available individual equipment, as well as how these items can influence core capability requirements. Spiral development, which is central to the RFI effort, focuses attention on rapidly developing technologies for immediate use and has enabled extraordinary advancement in Soldier lethality, force protection, and comfort by quickly distributing improved optics, weapons, and fabric technology to the force. SEP seeks to improve lethality, survivability, mobility, and sustainability of Soldiers by exploring and rapidly adopting commercially developed and available technologies in areas such as combat clothing, individual equipment, and shelters. (Lockhart, 2006) RFI brings the best that industry has to offer directly to the Soldier, items that in the past individuals had to purchase on their own including highly effective personal gear like gloves and socks. Soldiers in operational environments clearly felt like they needed these items to be effective and protected but the Army was not providing for them. (Crozier, 2006) The issue with RFI is that it is treated like an expeditionary requirement and dependent on current operations. As the operational tempo changes, the argument for funding RFI items is diluted. The potential for scarce defense dollars requires specific effort to ensure programs that provide for the tip of America's combat machine and the heart of the Army are adequately funded and resourced (Dawson, 2006).

## **4 Approach**

### **4.1 Human Component Perspective**

Given clear evidence as the impact of environmental conditions on Soldiers, this research seeks to develop a framework for evaluating the programs that provide environmental protection. Mitigating the impact with material solutions is the objective, but evaluating the material solutions with respect to performance is the challenge. Key to this effort is linking them to Soldier capability requirements and functions. Doing so with scientific evidence is difficult due to the variable nature of human performance and the

indirectness of the connections. For example, it is difficult to measure and quantify the impact on firing accuracy of a decline in manual dexterity due to cold conditions, even though it clearly is an issue.

Another key issue is emphasizing the fact that the human body is the fundamental component of the Soldier system. When it comes to programs that impact the human component, it's not about comfort, it's about Soldier performance. Further, not all material solutions are equal because some impact not just physical actions but also leader and Soldier decision making. Also, despite the inclination to discount comfort as an important factor, it is a Soldier satisfaction issue which may be linked to retention. Finally, it is important to recognize that these programs are not just for the current operational environment, even though they are funded as such. The future force must have the ability to dominate in any operational environment, and providing the appropriate clothing and individual equipment is critical to the success of that objective.

Soldier performance can be depicted as an input-output model as shown in Figure 1. The human is central to the weapon system. Assets and capabilities are added to enhance performance. However, two types of issues impact performance; those that can be controlled or predicted, such as food and water requirements, and those that cannot, such as the environmental conditions. Both the external inputs and the issues can be addressed with material solutions or by other means, but failure to do so may impact Soldier performance.

## 4.2 Value Focused Thinking

Concepts from the Value Focused Thinking (VFT) methodology were used in the development of an assessment framework because it focuses on objectives instead of alternatives (Parnell et al., 1998). VFT starts with identifying values and objectives, and then uses them to focus analysis, generate alternatives, evaluate, and decide (Keeney, 1992). The assessment framework is intended to help to determine the value of programs related to environmental pro-

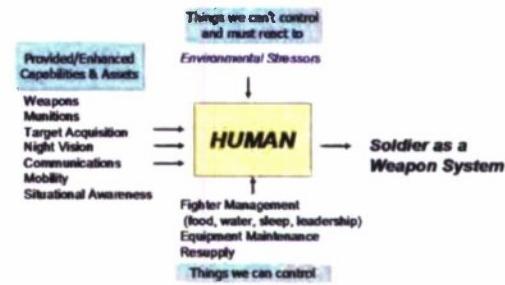


Fig. 1: Input Output Model

tection in terms of Soldier performance objectives, not to choose among a given set of options. Once the value is determined, then that information can be used to aid decision makers as appropriate.

A key element of VFT is the development of a value hierarchy, which identifies and organizes issues of importance to stakeholders and decision makers related to the system (Parnell et al., 1998). The first step is to determine the fundamental objective of the system, which becomes the focus of the assessment framework (Loerch and Rainey, 2007). In the case of the Soldier, based on various doctrinal references such as the Army Vision and the SaaS Initial Capabilities Document, the fundamental objective is to dominate the full spectrum of military operations in any environment (US Army Training and Doctrine Command, 2006; Office of the Chief of Staff of the Army, 2003; PEO Soldier, 2005; The Joint Staff, The Joint Staff). The next step according to VFT is to identify key functions of the system. These basic tasks must be accomplished to attain the fundamental objective. They are what the system does, its capabilities, and may be holistic or specific to a component of the system. Soldier functions include shoot, move, communicate, maintain situational awareness, and survive (US Army Training and Doctrine Command, 2006; PEO Soldier, 2005). These high level

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functions can be broken down into sub-functions and objectives that define value which can be measured, as seen in Figure 2.

Values describe what the system and its components must be, vice what it does. They are descriptive and applicable to all of the components of the system. Based on multiple doctrinal references, the values associated with the SaaS are versatile, responsive, deployable, interoperable, reliable, robust, sustainable, trained, effective, and efficient (Office of the Chief of Staff of the Army, 2003; PEO Soldier, 2005; The Joint Staff, The Joint Staff; US Army Training and Doctrine Command, 2006). Generally the next step in the VFT is the development of value measures with which to evaluate the attainment of system values as applicable to each function. However, with the SaaS, this must be done keeping the human component in mind.

In considering the functions and objectives of the SaaS, a key issue is the ability to operate in all environmental and climatic conditions. This is directly related to the fundamental objective as well as the values of the system, and is a condition for success in the functions. For example, the ability to engage and kill a target in a sterile, controlled environment is not enough. The Soldier must be able to do so in the cold, in the rain, etc. Certainly a big part of that capability is developed in training, but material solutions play a significant role in enhancing that capability, especially when considering long term operations in harsh environmental conditions. Thus, the influence of the environment on the human component of the SaaS and the impact of clothing and equipment on that influence must be taken into account when designing and providing for the system. An influence diagram illustrates the impacts associated with a system, as opposed to implying an order or hierarchy (Clemen, 1996). An influence diagram for the SaaS begins with its values and objectives, which are the foundation of the system. These values and objectives influence the equipment, clothing, protection items, and supplies that provide enhanced capabilities and that the Soldier needs to operate. In turn, these material solutions impact the human element, which is the fundamental component of the system, in

either a negative, marginal, positive, or transformative way. The human response to this influence can be physical, mental or psychological, and that influences the SaaS task performance. The individual tasks are aggregated into functions, so the performance level impacts the ability of the system to achieve its objectives, including ultimately the fundamental objective of dominating in any environment. Figure 3 illustrates the influence diagram for the SaaS.

### 4.3 Human Performance Objectives

Given the central role of the human component of the system, any effort to evaluate performance of the SaaS in the frame of environmental conditions must first consider the objectives in terms of the performance of the human. In order for the system to achieve its fundamental objective, the human element must be sustained in such a way that its objectives can be met. Figure 4 outlines some human component objectives.

Clearly, these objectives are not independent of each other. Cognitive performance is related to wellness, endurance is related to encumbrance, tactility is affected by the ability to stay warm, and so on. However, they do illuminate some key issues that material solutions can directly impact. Also, the linkage between metrics associated with some of these objectives and Soldier functions provides a pathway for quantifying the impact of items that provide environmental protection and enhance capabilities in harsh environmental conditions in a meaningful and comparable way for decision makers.

This effort will focus in on twelve human factors, drawn from the human component objectives. These include tactility, dexterity, critical thinking ability, cognitive acuity, cognitive agility, good judgment, emotional wellness, physical wellness, visual acuity, endurance, freedom of movement and quality of life. This list represents a mix of physical, mental, and emotional factors because all three impact human performance, particularly over the long term in high intensity environments. Table 1 is a table that provides definitions for the human factors of interest.

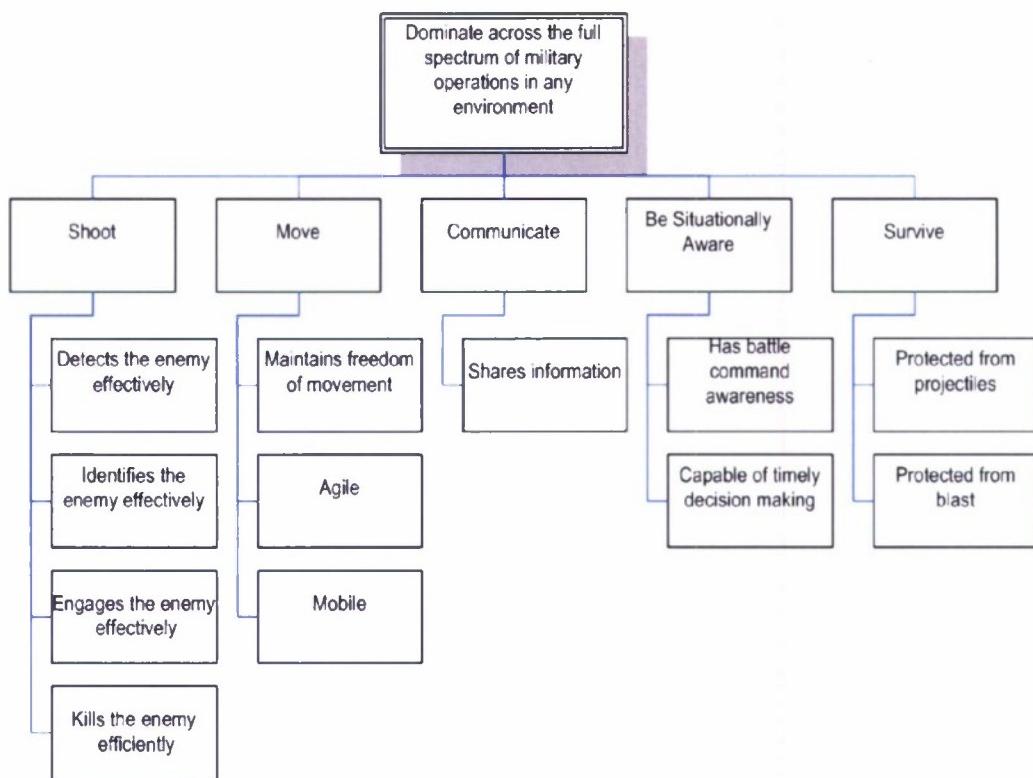


Fig. 2: Soldier Functions

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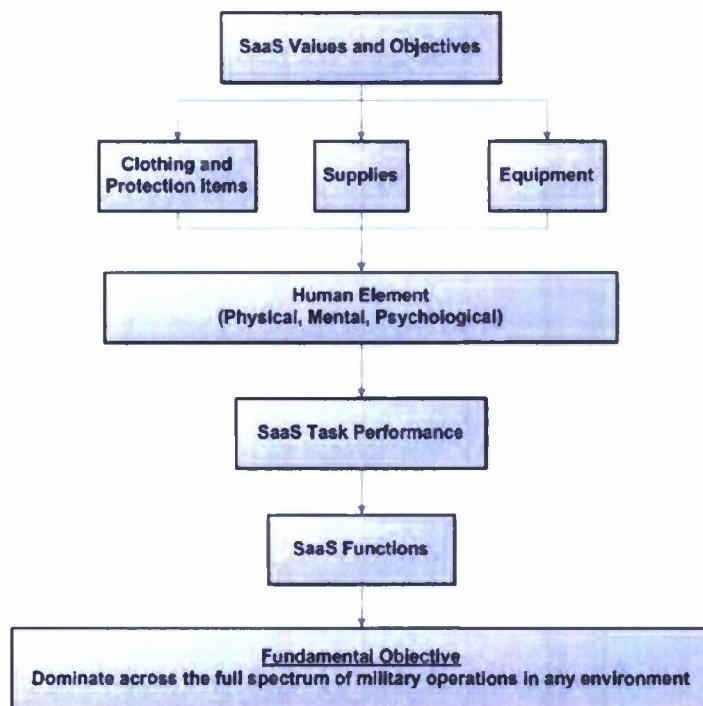


Fig. 3: Influence Diagram

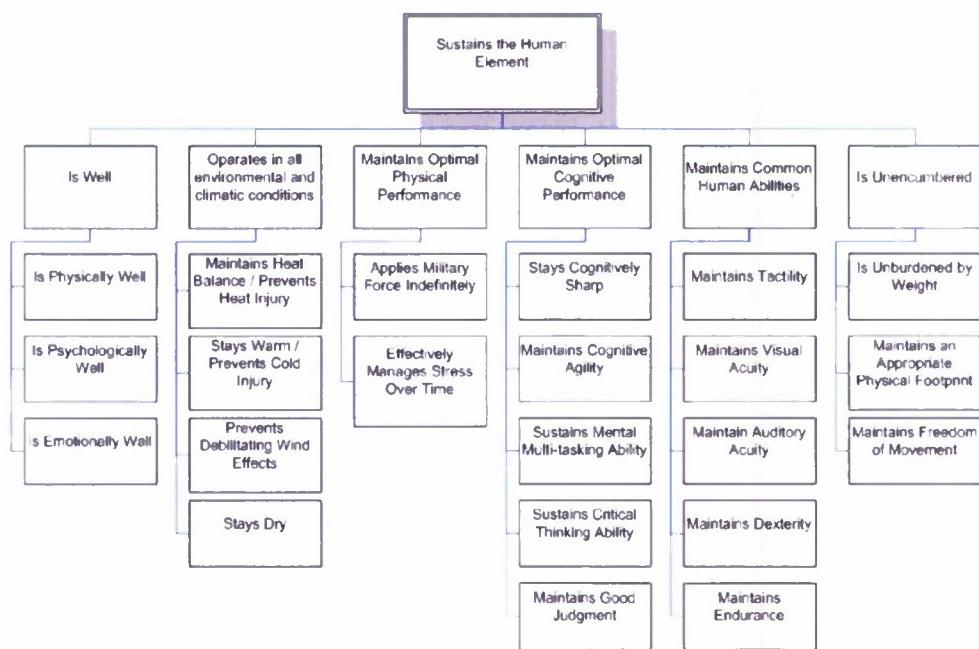


Fig. 4: Human Performance Objectives

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| Human Factor              | Description  |
|---------------------------|--|
| Tactility                 | Perceptibility by touch, sensitivity of touch  |
| Dexterity                 | Adroitness, skill and quickness with hands   |
| Critical Thinking Ability | Mental process of discernment, synthesis, evaluation, and decision-making.<br>Capable and purposeful reflective judgment.                          |
| Cognitive Acuity          | Mental keenness, ability to resolve fine details, sharpness of mind.   |
| Cognitive Agility         | Mental nimbleness, mental ability to move quickly and easily.  |
| Good Judgment             | Makes sound decisions  |
| Emotional Wellness        | Able to function and meet daily demands, feel capable and confident, able to manage emotional stress.  |
| Physical Wellness         | Able to function and meet daily demands, without pain or disease, able to recover from difficulty or stress, able to use capabilities effectively. |
| Visual Acuity             | Visual keenness, ability to resolve fine details, sharpness.   |
| Endurance                 | Strength to continue despite adverse conditions, exhaustion, pain, hardship, and/or stress. Perseverance.  |
| Freedom of Movement       | Ability to move unencumbered by weight, bulk, or ill-fitting worn items.   |
| Quality of Life           | Comfort, satisfaction, morale.   |

Tab. 1: Human Factors Definitions

### 4.4 If-Then-So Relationship

Critical to any assessment are the metrics used to evaluate the performance towards an objective. The challenge with the SaaS is demonstrating the impact human performance factors that are not inherently quantifiable. Thus it is necessary to design metrics that assign quantitative values to human performance impact using measures that provide a scale for use in the evaluation. In this case, the metrics are based on human body and aligned with the human factors. Some of the human body metrics apply to multiple human factors. Similarly, there is relationship between the human factors, which were derived from the human component objectives, and the SaaS functions. This linkage is called the “If-Then-So Relationship” which is based on this premise: If the Soldier has/can do/is X, then they will be/maintain/sustain Y, so they will be able to do Z. In this formula, X is the human body metrics, Y is the human factors, and Z is the SaaS functions. In this structure, the metrics represent states or conditions that can be quantified by using degrees or scales, such as a percent of time the condition is true or to what degree Soldiers agree with the statement.

The scales can be constructed so that they are specific to the capability of interest, depending on the information that the evaluation is trying to capture. That information is then translated into impact on human factors and Soldier functions, which are directly linked to performance. This is the framework for data collection that addresses the impact of clothing and individual equipment on Soldier performance. Figure 5 illustrates this concept.

## 5 Assessment

The use of this framework requires data collection regarding the impact of an item of clothing or individual equipment on the applicable human body metrics. This requires measures that are either directly related to the metric, such as volume or weight for questions of bulk or burden, or indicators for metrics that do not have direct measures, which can then be used to create constructed scales for use in surveys of users and subject matter experts. Examples of metrics that require indirect measures include questions of fit, comfort, ease of use, and effectiveness in combating a specific environmental condition, such as cold or wetness. This data can be collected by using feedback indicators.

### 5.1 Indicators

Three types of indicators may be useful in collecting data about the SaaS clothing and individual equipment. First is the supplementing indicator, which reflects the Soldier's preference for a specific item. In this case, a Soldier may purchase something that has the same function as what they are issued but prefer the specific performance characteristics. For example, given the prevalence and popularity of moisture wicking textiles in athletic wear, a Soldier may seek to purchase an ACU tee-shirt with those properties instead of wearing the standard cotton version. Usage is another indicator, by focusing on whether the Soldier actually used or wore the issued item. If it was a regular part of the uniform, when applicable, then that provides information as to the value and effectiveness of the item for the Soldier. Finally, the satisfaction indicator explores how much the Soldier likes an item, the "cool factor", and how satisfied they are with its performance in the intended function. This information may illustrate gaps in desired functionality as well as whether the Soldier feels like they are being taken care of and provided acceptable clothing and equipment to deal with difficult conditions in the long term. These indicators are frameworks for developing constructed scales that can be used to

survey users and experts regarding specific clothing and individual equipment items.

### 5.2 Surveys for Implementation

Developing the surveys based on indicators, measures and metrics is the first step in implementing the assessment framework. Data from the surveys and applicable direct measures can be used to determine the effect of the item of interest on the human body, which can then be translated into the effect on the SaaS function associated with the related human factors, as illustrated in Figure 6.

Also important to the assessment process is codifying the framework for specific items. For example, given gloves, the human body metrics from the If-Then-So Relationship would be 'has warm hands', 'is well fitted', and 'is unencumbered by bulk.' The human factors associated with these metrics for gloves would be tactility, dexterity, physical wellness, and quality of life. It is also important to explain the specific linkages between the metrics and the human factors. For example, it is important for gloves to be designed and sized to fit well. Otherwise the ability to accomplish tasks with the hands is affected because of the impact on dexterity. Also, quality of life may be indirectly affected because the Soldier may then choose to go without gloves that do not fit and be uncomfortable or possibly in pain as a result. Finally, the associated SaaS functions would be shoot, communicate, and operate in all environmental and climatic conditions. Again, as an example, a Soldier who is wearing gloves that do not fit well may have an issue with the trigger motion, compromising the firing technique required for accurate and effective shooting. This codification should be done for all general items that need to be evaluated in order to be used effectively by decision makers.

Finally, a data collection plan must be developed for the assessment. For a specific item, this should include specifications, design capabilities and limitations, and any initial technical assessments conducted if possible. Also, some post combat surveys or other operational test surveys may have useful information,

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### IF – THEN – SO Relationship

If the Soldier has/can do/is x, then they will be/maintain/sustain y, so they will be able to do z

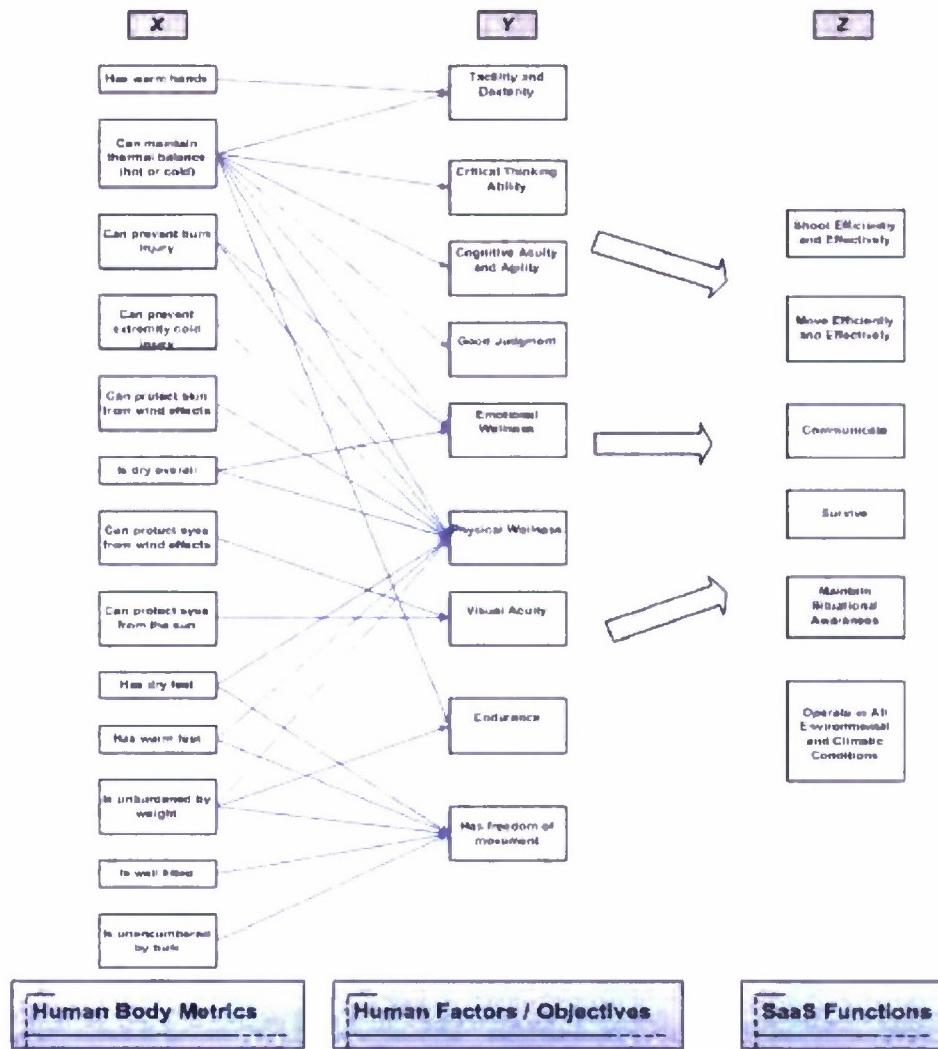


Fig. 5: If-Then-So Relationship

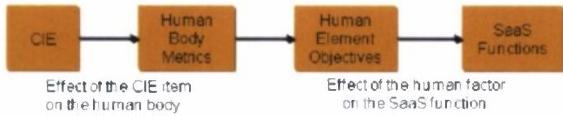


Fig. 6: CIE Impact on Functions

although they may require organization and analysis. However, the appropriate data for this framework can be collected using a survey focusing in on environmental factors and impact on Soldier performance, as well as the specific CIE items of interest. The survey plan must identify subjects, ideally from a re-deploying unit or Soldiers with recent experience with the items of interest, and the minimum number of data point needed to establish significance in the results.

## 6 Conclusions

This work has provided a framework for assessing the impact of CIE items on Soldier performance. Implementation of the assessment framework will require the direct and indirect data which can be used to determine the effect on the human body, which can then be translated into the effect on the associated SaaS function. This will require a full codification of the framework as well as a data collection plan for the survey process. The resulting indications of impact on Soldier effectiveness can be used to reinforce the SaaS concept in the program funding process and policy decision making.

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## Nomenclature

CIE Clothing and Individual Equipment

ECWCS Extended Cold Weather Clothing System

PEO Program Executive Office

RFI Rapid Fielding Initiative

SaaS Soldier as a System

SEP Soldier Enhancement Program

USARIEM U.S. Army Research Institute of Environmental Medicine

VFT Value Focused Thinking

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| <p>PEO Soldier has the challenge of integrating and equipping the Soldier as a System. However, some elements of the system remain consistently under-funded such as those that protect Soldiers from adverse environmental conditions, provide for health and comfort needs, support ergonomic requirements and ensure the ability of the Soldier to operate effectively in any environment for extended periods of time. At issue is the ability to quantify the impact of products that support the human component on Soldier effectiveness and capabilities. The intent of the Soldier as a System is to replace haphazard fielding efforts with an approach that treats the Soldier just like the other complex combat assets in the Army arsenal. The development of an assessment framework required the extraction of key functions and values of the system, a component of the decision analysis concepts applied to this problem, including value focused thinking. This concept will help PEO Soldier demonstrate the importance and value of programs that focus on the human component of the Soldier, particularly in adverse conditions.</p> |                |                            |                              |   |  |
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